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UNIVERSITY OF ALASKA

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Robert H. Armstrong

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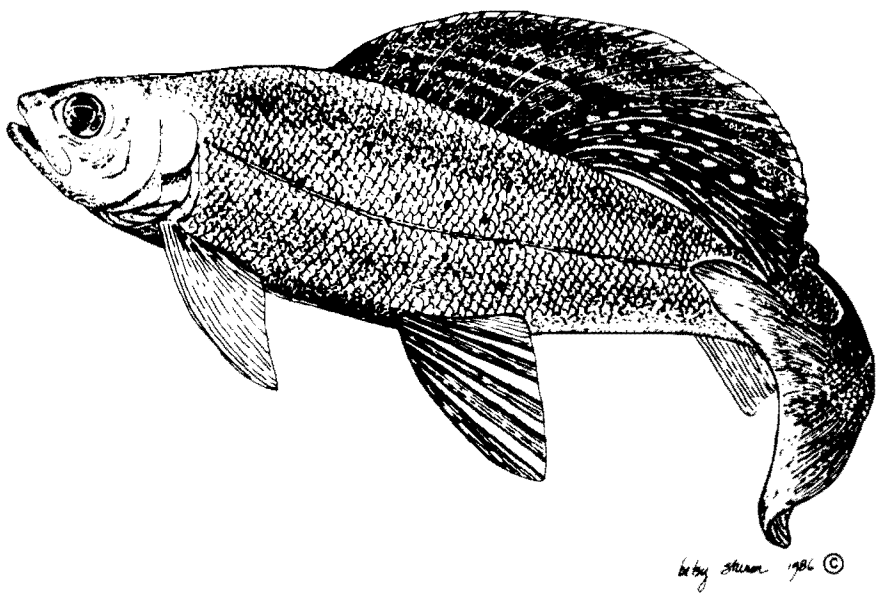
Robert H. Armstrong, Haakon Hop, and Julia H. Triplehorn



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A REVIEW OF ARCTIC GRAYLING STUDIES IN ALASKA, 1952-1982

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A REVIEW OF ARCTIC GRAYLING STUDIES IN ALASKA, 1952-1982

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INDEXED BIBLIOGRAPHY OF THE HOLARCTIC GENUS *THYMALLUS* (GRAYLING) TO 1985

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EDITOR'S INTRODUCTION

This issue of *Biological Papers of the University of Alaska* consists of two scholarly contributions on the biology and reference materials for fishes of the holarctic genus, *Thymallus*.

In Alaska, the genus is represented by the Arctic grayling, *T. arcticus* (Pallas), a species regarded highly by sportsmen throughout its range in Alaska (Mills 1979; see literature cited section of review article), especially in interior Alaska where it is the most popular sport fish (Holmes 1981). This popularity with anglers puts pressure on grayling populations, and in turn, pressure upon management agencies to regulate harvests and manage habitats used by Arctic grayling. Accordingly, the state and federal government agencies have compiled life history data on the species from a number of locations in Alaska since 1952. The Alaska Cooperative Fishery Research Unit, founded in 1978 at the University of Alaska, Fairbanks, made serious attempts to assemble and review systematically the growing number of unpublished research reports on Arctic grayling. The precursor for the review paper was the compilation of file reports, including 1,600 pages of collected research reports (Armstrong 1982). Thereafter, a synthesis appeared as an earlier draft of the review of Arctic grayling studies in Alaska, distributed on a limited basis as a processed report by the Alaska Cooperative Fishery Research Unit. Prior to these compilations and reviews, the most comprehensive assembly of grayling sources of information was the bibliography published by Vincent (1965) covering North American sources and titles through the early 1960s.

In the course of reviewing the research reports on Arctic grayling, Robert H. Armstrong discovered that significant gaps in life history information still existed. Some of these gaps could be filled provisionally by borrowing information from the similar palearctic species *T. thymallus*, for which Jankovic (1964) had provided a synopsis of biological information. Because approximately 20 years had elapsed since Vincent's (1965) bibliography of North American sources and Jankovic's (1964) synthesis of information of *T. thymallus*, Armstrong decided to broaden his bibliographic search to include holarctic information sources for the entire genus *Thymallus*. With the aid of Julia H. Triplehorn, Haakon Hop, and Sue Keller, the second contribution to this issue took shape, eventually resulting in the 1,314 titles included here. We therefore now have a good foundation for a worldwide review of the genus *Thymallus*.

The timeliness of both the grayling review and the *Thymallus* bibliography can be seen from an analysis of the

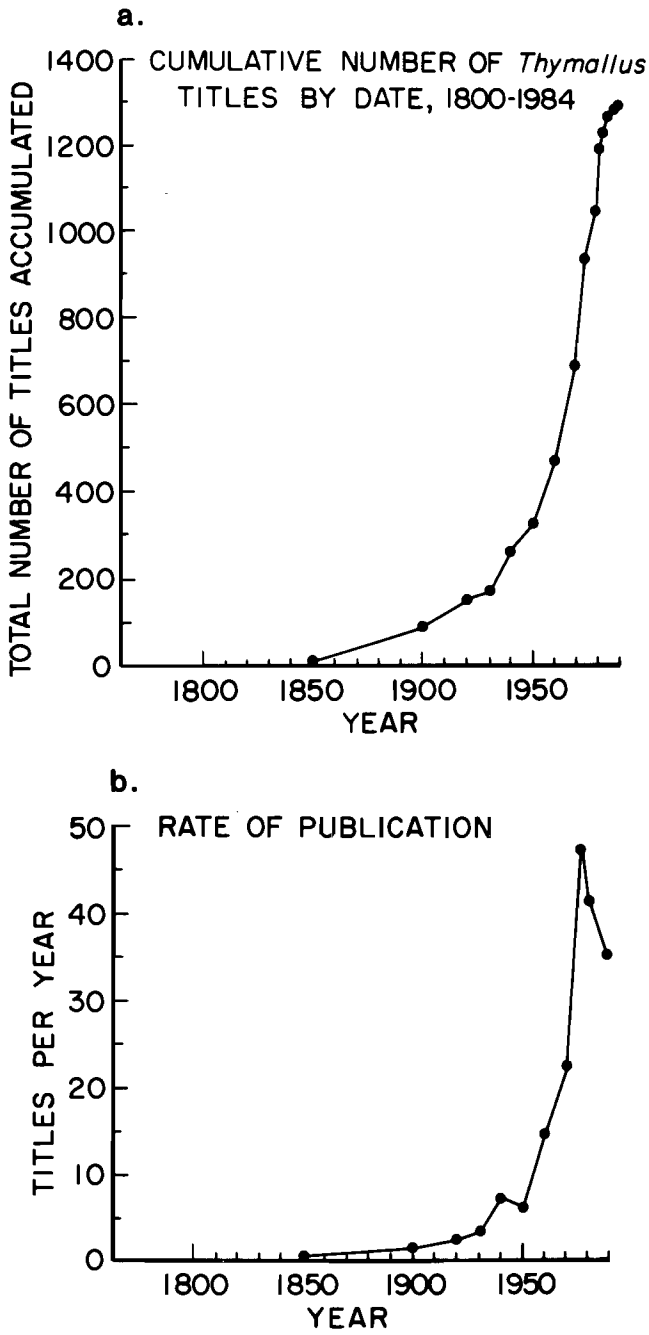

Figure 1 (*a*) Cumulative number of *Thymallus* titles by date, through 1984. (*b*) Crude annual rate of appearance of *Thymallus* titles obtained by dividing number of titles by number of years in periods ending in 1850, 1900, 1920, 1930, 1940, 1950, 1960, 1970, 1975, 1980, and 1984.

1,314 titles in the bibliography by date of appearance, both cumulatively (Figure 1*a*) and as a crude annual rate of publications on the genus (Figure 1*b*). Between 1965 and 1985, the literature (measured by number of titles) has more than doubled. The annual rate of new titles published jumped to its highest levels (48 per year) in the 5-year interval ending with 1975, having doubled over the previous 5-year period. The slight decline in rate of publication of new titles in the periods ending in 1980 and 1985 may be genuine, or it may be an artifact arising from time lags between publications and availability of titles in one of several search systems. In either case, the shapes of the curves in Figure 1 make it clear that 1985 was an appropriate year to attempt both the analytic synthesis of grayling biology and the worldwide *Thymallus* bibliography in a coordinated monograph.

D. W. Norton, June 1986

A REVIEW OF ARCTIC GRAYLING STUDIES IN ALASKA, 1952 - 1982

ROBERT H. ARMSTRONG[1]

ABSTRACT. Most information on studies of the Arctic grayling (*Thymallus arcticus*) in Alaska came from annual progress and performance reports of the Alaska Department of Fish and Game and reports of the Alaska Game Commission prepared before Alaska Statehood in 1959. Only a few reports have been published. Sport harvest, stocking, life history and population estimates are reviewed, and recommendations for further research are offered.

INTRODUCTION

Most studies of the Arctic grayling (*Thymallus arcticus*) in Alaska have been conducted under the Federal Aid in Fish Restoration Program. These studies were started in 1952 by the Alaska Cooperative Wildlife Research Unit at the University of Alaska, and were continued by the Alaska Game Commission (1953 to 1958) and the Alaska Department of Fish and Game (1959 to 1982). The results of these studies appeared in Federal Aid quarterly and annual reports, in one research report (Reed 1964), and in three Master of Science theses at the University of Alaska (Wojcik 1955, Schallock 1966, Vascotto 1970). In addition, a few studies were funded by the oil and gas industry in conjunction with development of the Alaska pipeline (McCart et al. 1972, Craig and Poulin 1974, de Bruyn and McCart 1974). More recent studies of Arctic grayling have been conducted by graduate students from the Alaska Cooperative Fishery Research Unit at the University of Alaska in Fairbanks (Grabacki 1981, Holmes 1981). Little of the information collected on Arctic grayling in Alaska has been published (notable exceptions are Reed 1964, Vascotto and Morrow 1973, Craig and Poulin 1975, and Schmidt and O'Brien 1982).

Much of the unpublished information on Arctic grayling is in Federal Aid annual reports. For instance, 161 Federal Aid annual reports from Alaska contain substantive material on grayling that totals more than 1,500 pages (Armstrong 1982). Although many Federal Aid reports are available, the information on grayling is often in reports with general titles that give little indication of their real content. Federal Aid reports written prior to Alaska Statehood in 1959 are difficult to find.

The present synthesis of life history information is thus based primarily on unpublished research reports of work conducted in Alaska. Secondarily, I have drawn on published or unpublished reports from work in nearby western Canada and elsewhere, when information on a particular topic was lacking in studies conducted in Alaska.

SPORT HARVEST

The Arctic grayling is one of the species most sought after by sport anglers in Alaska. In a survey of over 10,000 anglers who fished in Alaska in 1977, Mills (1979) asked that each list the species of fish in the order of fishing effort expended and personal preference. Statewide, Arctic grayling ranked third among species most frequently fished for, and fourth in order of preference. Fishermen who lived in the upper Copper-Susitna rivers and Arctic-Yukon-Kuskokwim regulatory areas ranked Arctic grayling as first in order of both fishing effort and preference. (Major river systems cited in the text are shown in Fig. 1.) A survey conducted by Holmes (1981) also showed grayling to be the most popular sport fish among anglers in interior Alaska.

Mills (1981) estimated that 170,137 Arctic grayling were harvested by anglers in 1980. Only the numbers of pink salmon (*Oncorhynchus gorbuscha*) and Dolly Varden (*Salvelinus malma*) plus Arctic charr (*Salvelinus alpinus*) exceeded the number of grayling caught by anglers in the state. The largest numbers of grayling—nearly half the total—were taken in the Tanana River drainage (Table 1). Nearly half of these fish, in turn, came from the Chena River drainage, where anglers took 41,825 in 1980 (Mills 1981).

Angler harvest can affect the structure of Arctic grayling populations by causing a decline in average size and age (Falk and Gillman 1974). Tack (1974) concluded that angler harvests may be responsible for grayling maturing at a smaller size in the Chena River than in other waters. Grabacki (1981) also concluded that the average size and age of grayling in the upper Chena River appeared to decrease in response to exploitation.

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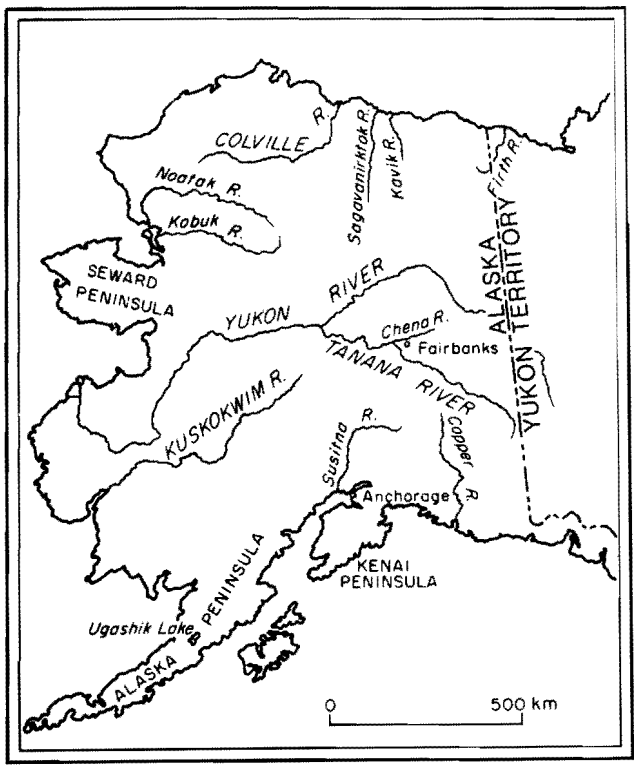

Figure 1. Natural habitat of Arctic grayling in Alaska, showing major drainages cited in text.

TABLE 1. ESTIMATED NUMBERS OF ARCTIC GRAYLING HARVESTED BY ALASKA ANGLERS BY REGION AND AREA, 1977-1980 (FROM MILLS 1981).

Area fished	1977	1978	1979	1980
Southeast				
Ketchikan	591	479	227	86
Prince of Wales Island	0	0	0	0
Petersburg-Wrangell	0	0	0	0
Sitka	17	18	18	9
Juneau	108	18	0	0
Haines-Skagway	59	154	36	34
Glacier Bay	0	0	0	0
Yakutat	0	0	0	0
Total	775	669	281	129
Southcentral				
Glennallen	25,991	26,488	37,232	32,106
Prince William Sound	0	0	0	0
Knik Arm drainage	3,916	2,413	8,371	9,514
Anchorage	187	0	18	77
East Susitna drainage	7,469	6,600	10,489	10,959
West Cook Inlet-West Susitna drainage	4,414	6,725	9,089	9,247
Kenai Peninsula	1,587	2,287	1,518	2,126
Kodiak	54	325	127	465
Naknek River drainage-Alaska Peninsula	808	614	609	1,550
Kvichak River drainage	826	1,438	873	1,421
Nushagak	496	976	1,990	1,997
Total	45,748	47,866	70,316	69,462
Arctic-Yukon-Kuskokwim				
Tanana River drainage	57,793	83,275	70,243	80,150
Interior Alaska	4,090	5,053	7,466	9,127
Seward Peninsula-Norton Sound	1,607	1,455	2,173	1,635
Northwest Alaska	1,407	1,997	2,145	1,790
South Slope Brooks Range	1,032	2,106	6,072	6,079
North Slope Brooks Range	1,239	678	1,373	1,765
Total	67,168	94,564	89,472	100,546
Alaska total	113,691	143,099	160,069	170,137

STOCKING

In Alaska, the development or improvement of the sport fishery for grayling has been attempted by stocking larval grayling from a hatchery, by pond rearing the fry for a few months before stocking them and by transplanting adult and subadult grayling from one aquatic system to another. Each of these methods has been successful in some waters and unsuccessful in others.

Stocking newly hatched fry from a hatchery into lakes has been most successful in barren lakes with suitable spawning streams (Van Wyhe 1963, Williams 1971). In a review of the stocking of grayling fry, Williams (1971) reported little or no survival when predator species were present. Grayling stocked in lakes containing northern pike (*Esox lucius*) have not survived (Tack 1972). On the other hand, Van Hulle and Murray (1975) found that stocked grayling fry competed successfully with fingerling rainbow trout (*Salmo gairdneri*) that were stocked about one month later in a previously barren lake. One year later the grayling were 20 mm longer and 1.4 times heavier than the rainbow trout. Stocked grayling may also compete successfully with the lake chub, *Couesius plumbeus* (Roguski and Tack 1970).

Some fry plantings in barren lakes have been very successful, resulting in the development of self-sustaining populations that have provided good sport fishing. Planted fry occasionally show phenomenal growth of more than 200 mm in length in a single growing season (Van Wyhe 1963, Williams 1971). Others, especially those stocked in shallow ponds and small lakes, have often been unsuccessful, despite good growth rates. Lack of oxygen and suitable spawning areas, and presence of other fish species, are usually cited as the main reason for failure (Roguski and Tack 1970; Tack 1972, 1973). The stocking of fry into various shallow lakes has shown that some grayling overwinter despite the reduction of dissolved oxygen concentrations to less than 1 ppm (Roguski and Tack 1970). Williams (1972), after examining a winter mortality of fish in Tolsona Lake (Copper River drainage) where dissolved oxygen was 0.5 ppm, concluded

that grayling were more tolerant of low oxygen than either burbot (*Lota lota*) or longnose suckers (*Catostomus catostomus*). Lakes considered unsuitable for trout because winter oxygen concentration drops as low as 1 to 2 ppm may be adequate for overwintering grayling (Heckart and Roguski 1966).

Stocking newly hatched grayling into rivers has not been successful. Over 300,000 grayling fry have been stocked into the Delta Clearwater River (Tanana River drainage) with no apparent survival (Kalb and Peckham 1975, Pearse 1976). Stocking was successful, however, when the fry were reared in ponds for about 3 months before they were stocked in the rivers. Shortly after hatching in June, the fry were stocked into shallow ponds and reared until late September or early October, when they were effectively removed (99%) with fyke nets (Peckham 1977, 1978). Survival rate in the ponds ranged from 5 to 34% (Peckham 1978) and most fish were over 100 mm long at the time of removal (Pearse 1976). The fingerlings were then stocked into spring-fed areas of the Delta Clearwater River. Studies by Pearse (1976) showed that the pond-reared grayling had a larger number of first-year circuli on their scales ($\bar{x}=14$) than did the grayling naturally occurring in the Delta Clearwater ($\bar{x}=8.7$). This difference enabled biologists to determine the percentage contributions of the stocked fingerlings to the fishery by examining scales from fish taken by anglers. Evaluations of this project are still under way, but Ridder (1980) found that 60% of the age-4 grayling in the creel were stocked and that these fish accounted for 23% of the total catch.

Transplanting adult and subadult grayling into barren lakes has been successful in establishing new sport fisheries. In 1952, 240 grayling were transplanted to Crescent Lake on the Kenai Peninsula (Engel 1965). This single transplant resulted in a sport fishery that is still self-sustaining. In 1972, Crescent Lake supported a spawning population of more than 1,700 grayling and their growth rates were better than those of interior stocks and comparable with those of the trophy grayling of Ugashik Lake (Engel 1973). Grayling from Crescent Lake have been transplanted to several other Kenai Peninsula lakes, in most of which they have established self-sustaining populations (Engel 1970, 1971).

LIFE HISTORY

Reproduction

Most grayling populations in Alaska spawn from mid-May to mid-June, although some have been found spawning in late April and others in early July (Wojcik 1954, Warner 1955, Schallock 1966, Roguski 1967, Roguski and Tack 1970, de Bruyn and McCart 1974, Tack 1974, Bendock 1979). Water temperature and spring flooding may be factors that stimulate grayling to spawn. According to Tack (1973), a water temperature of around 4 °C triggers grayling spawning in the interior streams of Alaska. Alt (1976) also suggested that 4 °C was the temperature at which most grayling in western Alaska began spawning. In northern Alaska the spawning period often coincides with the arrival of the flooding, turbid water of spring breakup (de Bruyn and McCart 1974). In the Tanana River drainage, Schallock (1965) also found grayling spawning during the spring flood of the Chatanika River, when the water was turbid. By contrast, Warner (1955) found that grayling spawned in the inlets to Fielding Lake in pools of open water when the water temperature was about 4 °C, while many streams were still covered with ice and snow.

Grayling spawn in main stem rivers, in large and small tributaries to rivers and lakes, in intermittent streams, and in lakes—usually at the mouths of tributaries (Warner 1957, Bendock 1979). In rivers and streams, grayling have been found spawning mostly in riffle areas of pea-sized gravel (Warner 1955, Tack 1971). Although gravel measurements have not usually been taken where grayling have been observed spawning, Tack (1973) reported that most spawning was over gravel between 0.075 and 38.1 mm in diameter. In Montana, where Nelson (1954) took stream bottom samples to determine the abundance of grayling eggs in relation to bottom material, no eggs were found over sand and silt or in pools; all were in riffles composed of gravel or rubble.

Although gravel in riffles appears to be the most commonly selected spawning site for grayling, other sites have been reported. In an inlet of Fielding Lake, Wojcik (1954) mentioned that grayling spawned primarily in slow shallow backwater areas. In some northern Alaska lakes they spawned in the lake itself over substrates ranging from large rubble to vegetated silt (Bendock 1979); they have also been seen spawning among sedges over an organic bottom in a nearly stagnant pond (Tack 1980) and over mud in a slough (Reed 1964).

The spawning of grayling was described by Tack (1971), who wrote that males established territories in the riffle areas while the females remained in deep pools and entered the riffles only for short periods to spawn. Tack described 22 male territories as being generally oval, 6 to 8 feet wide and 8 to 10 feet long. Average water depth over these territories was 1 foot (range 0.6 to 2.4 feet) and average water velocity was 2.6 fps (range 1.1 to 4.8 fps).

Tack (1971) described the spawning act as follows:

> When a female comes into the riffle, males from territories near her erect their dorsal fins and move laterally toward her. The female may pass up several males before responding to a male display. A female responds by erecting her dorsal fin and moving laterally toward the displaying male. The undulations intensify as the fish come closer. As their bodies come in contact, the undulations become more intense, the male leans

> toward the female so his dorsal fin covers her back, and the male's caudal peduncle crosses over that of the female. The force of the male's caudal fin, working now in a vertical direction because of his body tilt and slight axial twist, drives the posterior portion of the female's body down into the gravel. After a spawning act the posterior third of the female's body is usually buried in the gravel. About halfway through the spawning act, the female opens her mouth widely, displaying the dark slash on her throat. The male also gapes, starting a second or two after the female.

The described forcing of the posterior portion of the female grayling's body into the substrate apparently results in the eggs being deposited below the gravel surface. Van Wyhe's (1962) observations of 172 pairs of spawning grayling showed that the eggs were deposited at a depth of about 2.5 cm. Others have also observed that grayling eggs are buried to a depth of 2 to 3 cm (Kratt and Smith 1977). Many eggs may be washed downstream because of this relatively shallow depth of burial (Warner 1955).

Other observations of grayling spawning include a report by Van Wyhe (1962) that most spawning occurred between 8 p.m. and 2 a.m., when the spawning area was not exposed to sunlight. Engel (1973) mentioned that males remained on the spawning grounds longer than females.

Embryonic development is rapid. At a water temperature of 8 °C, embryos became eyed in 14 days and hatched in 18 days. At an average temperature of 15.5 °C eggs hatched in 8 days (Wojcik 1955). In a study of the Arctic grayling in northern Saskatchewan, Kratt and Smith (1977) found that grayling eggs hatched in 186.24 degree-days. After hatching, the alevins remained in the gravel for only 3 to 4 days. Kratt and Smith also reported that the newly hatched fry had almost completely absorbed their yolk sacs by the time they left the gravel.

De Bruyn and McCart (1974), who studied the ovarian development of grayling eggs, reported that egg diameters averaged less than 0.5 mm in the ovaries of recently spawned fish and were 1.7 mm by mid-September and 2.0 to 2.5 mm just before the spawning season in spring. Both female and male grayling in Alaska spawn every year after they reach sexual maturity (Williams 1969, Engel 1973, de Bruyn and McCart 1974).

Fecundity of Alaskan grayling appears to vary depending on the size of fish and locality. Schallock (1966) found that the number of eggs ranged from 1,700 for a fish 267 mm long to 12,350 for a fish 400 mm long among 24 females with an average fecundity of 5,350 eggs. In the Yukon Territory, de Bruyn and McCart (1974), who examined 20 females from three localities, reported a mean fecundity of 8,968 eggs (range 4,077 to 14,429). When the samples were combined and subjected to a regression analysis, however, they found a correlation coefficient of only 0.15. Tack (1971) also gathered data that suggest a poor correlation between number of eggs and length of Arctic grayling.

Young-of-the-Year

Larval grayling, before formation of the dorsal fin rays, are difficult to identify, and no references to the identification of larval freshwater fish in Alaska could be found. Schallock (1966) suggested that week-old grayling larvae resemble "two eyeballs on a thread," but other larval fish that occur with the grayling, such as round whitefish (*Prosopium cylindraceum*) and longnose sucker, also fit this description. After they reach a length of about 20 mm, the larval grayling can be distinguished from other similar-sized larval fish by the newly developed longer dorsal fin with 17 to 25 rays.

In streams, after emerging from the gravel, young grayling live in areas of quiet water. They occur in very shallow riffles between rocks at the lower end of gravel bars (Vascotto 1970), in backwaters, in side channels (Tack 1971, McCart et al. 1972, de Bruyn and McCart 1974), and in quiet side pools and brushy or grassy areas of adjacent sloughs (Alt 1976, 1980). They remain in these quiet water areas, often in dense schools, until later in the summer when they become territorial and solitary and move into deeper water (Vascotto 1970, de Bruyn and McCart 1974). Later, in early fall, they may leave the headwater areas and smaller streams and enter larger rivers, lakes, or (on the North Slope) spring-fed areas for overwintering. At Poplar Grove Creek (Mile 136 Richardson Highway, in the Copper River drainage) young-of-the-year grayling began an outmigration in early September and by 19 October 62,000 fish had passed through weir traps (Williams and Morgan 1974). Reed (1960) mentioned that young-of-the-year grayling drift out of the headwater streams of the Chatanika River in the early fall. On the North Slope, young-of-the-year grayling have been reported leaving small tundra streams in August and September (McCart et al. 1972, Craig and Poulin 1975). At Weir Creek, a tributary to the Kavik River, the outmigration of fry peaked between 13 and 21 September (Craig and Poulin 1975).

Little is known about the habitats selected by young-of-the-year grayling associated with lakes. De Bruyn and McCart (1974) suggested that in lakes with inlet or outlet streams, the fry remained in the streams in summer and moved into the lakes to overwinter. The habitat for the offspring of grayling that spawn in lakes, as reported by Bendock (1979), is unknown.

Fry living in streams may be subject to extremely high mortality under conditions of flooding or drought. Nelson (1954) mentioned that fry are helpless in water currents for two weeks after hatching. Flooding at this time and probably even later could wash the young out of their rearing areas, causing either direct mortality due to turbulence or indirect mortality due to the fry being swept into unfavorable rearing areas. Tack (1974) suggested that the Chena River flood of 1967 caused heavy mortality among young-of-the-year, because that year class was missing in samples taken in later years. Flooding of the Chena River in July 1981 may also

have caused heavy mortality, as few grayling fry could be found in locations where they had been reported as abundant in previous years (Robert Walker, Alaska Cooperative Fishery Research Unit, pers. comm.). During droughts, falling water levels often trap young grayling in shallow pools isolated from the main stream (de Bruyn and McCart 1974).

Migrations

Tack (1980) summarized what is known about the migration of Arctic grayling in the interior and arctic portions of Alaska. Most of the information on migration presented here is from his work or my interpretation of it. Tack believed that in interior Alaska the source of water in a river or stream affects its use by grayling within these systems: glacier-fed systems tend to be used mainly for overwintering or as migratory routes to other systems, spring-fed systems mainly for feeding but not for spawning or overwintering, bog-fed systems for spawning and feeding but not for overwintering, and large unsilted runoff systems for all purposes—spawning, feeding, and overwintering. Grayling living in a lake may move into either the outlet or inlet to spawn. In systems entering the Arctic Ocean, spring-fed areas of the larger rivers may provide the only available overwintering habitat for river-dwelling grayling.

Grayling are able to adapt to such a wide variety of waters because they spawn in spring and early summer and their eggs and larvae develop relatively fast. This early and rapid development enables the young to leave systems before they become frozen and uninhabitable in winter. These adaptations to different systems or different parts of the same system sometimes result in rather complex migrations to overwintering, spawning, and feeding sites, as briefly described below.

Migrations to Overwintering Areas

In fall, entire populations of grayling migrate downstream and out of certain tributaries and enter the Yukon, Kuskokwim, and Tanana rivers for the winter. They leave the bog-fed tributaries, most of which freeze solid or dry up during winter, and most also leave the spring-fed tributaries. It is not known why grayling leave spring-fed tributaries, which contain well-oxygenated open water and abundant larval insects all winter. A possible reason is that these systems often form extensive frazil ice in winter (Steve Tack, Fairbanks, Alaska, pers. comm.). Frazil ice forms throughout the water column as minute, irregular crystals (Maciolek and Needham 1952) and may lodge in the gills of fish, causing mortalities (Tack 1938); or it may become so thick that the water is uninhabitable. Although young silver salmon (*Oncorhynchus kisutch*) and slimy sculpin (*Cottus cognatus*) overwinter in spring-fed rivers, their survival may be closely tied to their ability to escape frazil ice by inhabiting the spring areas.

In the Arctic, grayling living in streams must migrate to overwintering sites containing extensive groundwater because most of the rest of the stream may freeze completely. Grayling may migrate either upstream or downstream to these spring areas, depending on their location in relation to the summer distribution of the fish.

In the larger unsilted runoff rivers of the interior, such as major tributaries to the Tanana River (Chena, Goodpaster, and Chatanika), most grayling inhabiting the upper reaches and tributaries migrate downstream to overwinter in the deeper water of the main stem; some fish may leave the system to overwinter in the Tanana River. Some grayling begin migrating as early as mid-July but most are believed to begin moving in September; some may even leave headwater tributaries as late as December.

Grayling also overwinter in lakes. Movements to these lakes may be either upstream (from outlets) or downstream (from inlets), and may occur early in the summer—especially if the streams are small and used mainly for spawning.

The distance that a grayling must migrate to reach an overwintering area varies considerably from one system to another. Some grayling may spend part or all of their lives within the immediate vicinity of overwintering areas; these fish may include stocks associated with certain lakes, those living near major groundwater sources, and perhaps some of those that spawn in the main stem areas of the larger unsilted runoff rivers such as the Chena. Other grayling may migrate from a few kilometers to between 130 and 160 km to reach overwintering sites. Grayling inhabiting the upper reaches of spring-fed systems and some runoff systems in interior Alaska may migrate long distances to reach overwintering areas.

Migrations to Feeding Areas

Migrations to feeding areas may vary depending on the age of grayling, type of system in which they overwinter, and the type of system in which they spawn. Young-of-the-year grayling are believed to spend the first summer feeding in the vicinity of their natal area.

Grayling that enter or migrate to feeding areas in unsilted rapid-runoff rivers tend to go to different areas, depending on their age and maturity: Juveniles (ages 1, 2, and 3) move into or remain in the lower portions of these rivers and their tributaries; the subadults (ages 4, 5, and sometimes 6) tend to move to the middle portions of the rivers; and post-spawning adults either move upstream to feed in the upper reaches of the rivers or, if they spawned in the upper reaches, remain there throughout the summer.

Grayling migrations to feeding areas of the spring-fed systems in interior Alaska are more complex. Since the fish generally do not overwinter or spawn in these systems, the entire summer feeding population must originate elsewhere. Many juveniles and subadults probably move into the spring-fed systems directly from their overwintering areas within

TABLE 2. PERCENTAGES OF GRAYLING SEXUALLY MATURE AT DIFFERENT AGES IN SAMPLES FROM SELECTED WATERS IN ALASKA

Age (years)	Chena River [a]		Mineral Lake Outlet [b]		Goodpaster River [c]		Happy Valley Creek [d]		Colville River [e]		Ikagiak Creek [e]		Kiruktagiak River [e]	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0	30	0	—	—	—	—	—	—	7	0	—	—	—	—
1	41	0	—	—	—	—	2	0	5	0	—	—	3	0
2	41	0	2	0	—	—	24	0	4	0	9	0	8	0
3	17	0	11	0	—	—	10	0	6	0	5	0	4	0
4	51	86	32	9	11	0	14	7	2	0	5	0	4	0
5	77	100	11	64	26	23	4	0	7	14	3	0	4	0
6	32	100	5	100	22	73	8	63	7	0	4	0	7	29
7	15	100	6	100	12	100	6	67	7	71	4	0	10	50
8	—	—	1	100	6	100	4	100	6	100	8	25	2	100
9	—	—	1	100	8	100	8	100	6	100	4	100	3	100
10	—	—	—	—	4	100	8	100	2	100	3	100	—	—
11	—	—	—	—	1	100	6	100	—	—	—	—	—	—
>11	—	—	—	—	—	—	15	100	—	—	—	—	—	—

[a]Van Hulle (1968) [b]Tack (1971) [c]Tack (1974) [d]McCart et al. (1972) [e]Kogl (1971)

the large glacier-fed systems. Others move into the spring-fed systems after having entered other streams for spawning or short-term feeding. Most of the fish feeding in spring-fed systems may have first entered bog-fed systems to spawn. Adults are known to leave most bog-fed systems soon after spawning and migrate elsewhere to feed. Tagging studies have shown that many of these adults enter spring-fed systems after spawning. Also, subadult grayling, especially the larger ones, leave the bog-fed systems in early summer and feed elsewhere—probably in spring-fed systems. By contrast, young-of-the-year grayling may remain and feed in bog-fed streams all summer.

Migrations to Spawning Areas

Most adult grayling leave their overwintering areas and enter a bog-fed or unsilted rapid-runoff stream to spawn (Tack 1980). Only in large unsilted rapid runoff rivers do grayling spawn in the same stream in which they overwinter; even in these rivers most grayling migrate upstream to parts of the system not used for overwintering. This migration appears to be associated with a rise in water temperature to about 1 °C. Consequently it may begin as early as mid-April in some southern interior streams and as late as early June in northern Alaska. In lakes, grayling may move into either the inlet or outlet to spawn, but usually not both.

Homing to Spawning and Feeding Sites

Grayling probably return to the same river annually to feed. Of over 1,000 recaptures made a year or more after release in the Delta Clearwater and Richardson Clearwater rivers (Tanana River tributaries), 99% and 96%, respectively, were made in the same rivers in which they were tagged (Tack 1980). This site fidelity is of special interest because few grayling either spawn or overwinter in these systems. It thus appears that they return, after leaving the system, for the sole purpose of feeding.

Although homing to specific spawning areas has not been established for Arctic grayling in Alaska, Tack (1980) believed that the annual site fidelity of grayling adults to feeding streams suggests similar homing to spawning streams.

Age

Validity of Aging Techniques

The age determination of Arctic grayling from scales may not be reliable for older fish. The interpretation of annuli after age 5 is difficult because the growth rate slows and the consequent crowding of circuli forms a dense edge (Roguski and Winslow 1969, Roguski and Tack 1970, Engel 1973). Comparisons of ages determined from scales with those determined from otoliths of the same fish have shown that both methods give similar ages through age 7 or 8, but that the scale method tends to underestimate the ages of older fish (McCart et al. 1972, de Bruyn and McCart 1974, Craig and Poulin 1975). For example, Craig and Poulin (1975), in a comparison of age estimates for grayling from Weir Creek and Kavik River, found no fish older than age 11 by using scales, but several up to age 16 by using otoliths. For Happy Valley Creek, McCart et al. (1972) also found no grayling over age 11 by using scales but several up to age 20 by using otoliths. Grayling over age 7 taken from the Firth River and Trout Lake in Yukon Territory also showed differences in age, depending on the method used. For instance, the maximum ages determined were 22 in the Firth River

and 15 in Trout Lake by the otolith method and 14 and 11, respectively, by the scale method (de Bruyn and McCart 1974).

Otoliths usually continue to develop fairly clear annuli throughout the life of the fish, whereas scales develop a "dense edge" (Nordeng 1961) that tends to obscure the annuli (de Bruyn and McCart 1974). Consequently most of the studies on age and growth of grayling in Alaska, of which only a few have been based on otoliths, must be interpreted carefully. Studies of growth rates up to age 7 or 8 and of age at first maturity should be valid when the investigators used scales, but estimates of growth rates of older fish and of longevity are probably not valid.

Scale formation begins at a fork length of about 35 to 38 mm in the Chena River (Tack 1974) and at about 35 mm on the North Slope (de Bruyn and McCart 1974). In some areas grayling may not reach 35 mm by the end of their first growing season, and thus may not have formed scales. Tack (1975) suggested that some young grayling from the upper Chena River fail to develop scales in their first year, and McCart et al. (1972) made similar observations in the upper Atigun River. This possibility should also be considered when one attempts to age Arctic grayling by their scales.

Age and Size Maturity

The age at which most grayling first mature may vary from one river system to another (Table 2). In the systems examined in Alaska, most grayling mature from ages 4 to 8. Most grayling have matured by age 4 to 6 in the interior systems, but not until ages 6 to 9 in the North Slope systems.

Maturity of grayling is probably more closely related to size than to age. Unfortunately, most studies do not present data in a form that shows the relation of size to maturity by specific age groups. Some insight into this relation can be gleaned from the study of grayling in the Goodpaster River by Tack (1974). Among age-5 fish most of those 290 mm long (fork length) or longer were mature, whereas most shorter than 290 mm were immature (Table 3). This relationship also held for age-6 fish. On the North Slope, all mature grayling from the Kavik River drainage exceeded 295 mm in fork length (Craig and Poulin 1975). Other studies of grayling maturity on the North Slope, though not giving precise data on length at maturity, suggest that maturity is more dependent on size than on age (Kogl 1971). Grayling that mature at a later age (e.g., in the Colville River) also have a slow growth rate. In western Alaska grayling reach maturity at about 300 mm in the Anvik River (lower Yukon River drainage), and all fish of age 6 sampled from this system and from Pilgrim River (Seward Penninsula) and Feniak Lake (Noatak River drainage) were mature (Alt 1978, 1980).

The only exceptions to the generalization that most grayling mature at a length of 290 to 300 mm are in populations

TABLE 3. LENGTHS AND AGES OF GRAYLING FROM THE GOODPASTER RIVER THAT WERE SEXUALLY MATURE (MODIFIED FROM TACK 1974)

Fork length (mm)	Age (years)					
	5		6		7	
	No.	%	No.	%	No.	%
<250	2	0	—	—	—	—
250-259	4	0	—	—	—	—
260-269	5	20	—	—	—	—
270-279	2	0	2	0	—	—
280-289	4	25	4	25	—	—
290-299	6	67	1	100	—	—
300-309	1	0	4	75	1	100
310-319	—	—	6	100	1	100
320-329	1	100	2	100	2	100
330-339	1	100	3	100	2	100
340-349	—	—	—	—	5	100
>350	—	—	—	—	1	100

of the Chena River and Mineral Lake (upper Tanana River drainage), where most mature at 270-mm fork length (Tack 1974). Tack speculated that the maturation of fish at smaller sizes may be related to heavy angler harvests in some river systems and that the long-term harvesting of the larger fish by anglers has caused a genetic shift in the population, favoring maturity at a smaller size. Early comparative data from the Chena River and Mineral Lake are not available to test this hypothesis.

Age at maturity appears to be similar for males and females. Although most sample sizes were too small to support a sound analysis of maturity by age and sex, I found no indication that males and females differed in this respect from the data presented (Tack 1971, 1974; McCart et al. 1972; de Bruyn and McCart 1974; Craig and Poulin 1975).

Age Composition and Longevity

As previously mentioned, the estimation of longevity and age composition from scales is probably not valid because annuli are difficult to interpret in older age groups. Also, a particular collecting method may sample certain age groups in disproportionate numbers. For instance, electroshocking may undersample the smaller fish, and angling may oversample the larger fish. Despite these shortcomings, some general conclusions can be drawn by summarizing the age composition data collected from certain systems in Alaska (Table 4). The Chena, Delta Clearwater, and Goodpaster rivers were sampled by electroshocker; whereas the Kavik River, Weir Creek, and Happy Valley Creek were sampled by a variety of methods, including hook and line, seine, fyke net, back-pack shocker, and weir.

Because compositions vary considerably from one stream system to another, extrapolation of the results from one

TABLE 4. PERCENTAGE AGE COMPOSITION OF ARCTIC GRAYLING SAMPLED FROM SELECTED WATERS IN ALASKA AND THE YUKON TERRITORY.

Age (years)	Chena River[a]	Delta Clearwater River[b]	Goodpaster River[c]	Kavik River & Weir Creek[d]	Happy Valley Creek[e]
1	37	1		19	
2	23	4	3	10	50[g]
3	18	13	45	14	
4	13[f]	19	27	9	
5	4	19	13[f]	8	
6	3	25	5	7	
7	2	13[f]	4	16	
8		3	1	8[f]	39[g]
9		1[g]	1	2	
10			1[g]	2	
11				2	
12				1	
>12				1	10[f]
n	201	534	298	252	119

[a] Van Hulle (1968)
[b] Peckham and Ridder (1979)
[c] Tack (1974)
[d] Craig and Poulin (1975)
[e] McCart et al. (1972)
[f] The youngest age that included at least 90% of the fish
[g] Fish with a range of ages were grouped together

system to others is not valid. One cause of variability could be selective angling mortality among the older fish. For instance, the Chena River supports the largest grayling harvest in Alaska; more than 35,000 fish are taken by anglers in some years (Mills 1981). This river has the lowest percentage of older fish of any system reported in Alaska. By contrast, systems like Happy Valley Creek and the Firth River that have yielded only a light sport harvest had the highest percentages of fish in the older age groups. Average size and age of grayling may decrease where the fish are exploited—as indicated in a study by Grabacki (1981) on the Chena River. Life history differences of grayling in certain systems can also affect age composition. For instance, the Delta Clearwater River is mainly used by grayling for summer feeding and not for spawning or rearing. Thus, few 1- and 2-year-olds are found in this river. Also, certain portions of some rivers harbor mostly immature fish, whereas other parts contain mostly adults. For instance, the east fork of the Chena River contains a much higher percentage of adults than does the main stem—perhaps because the east fork is used more for spawning of adults and the main Chena for rearing. Selective angling mortality on the much more heavily fished main stem may also be a factor. In any event, the age composition data presented in Table 4 for the Chena River were drawn from samples taken in the main stem and therefore do not reflect the age composition of grayling throughout the river.

Growth

Few studies have been conducted on first-season growth of young grayling, and no reference to the size of newly hatched grayling in Alaska could be found. In a study of hatchery grayling in Montana, Watling and Brown (1955) found that newly hatched fry were 9.4 to 13.2 mm long and averaged 11.3 mm. In the Chena River, grayling that have completed yolk sac absorption are about 14 to 15 mm long (Robert Walker, pers. comm.).

In some streams, growth during the first year of life may depend more on the time of hatching, and hence on the length of the growing season, than on feed or water temperature after hatching. De Bruyn and McCart (1974), who compared the mean fork lengths of grayling fry collected from nine streams on the Yukon North Slope, could find no correlation of lengths to the amount of benthos or the stream water temperature. Although one would expect a faster growth rate among fry living in areas with the most food and a high water temperature, a longer growing season may produce the larger fry. Also, the length of fry collected on similar dates may vary considerably from one site to another within the same stream. Tack (1975) found that the mean size of young-of-the-year grayling in the Chena River declined as one moved upstream. Growth during the first summer varies among systems, resulting in year-end fork lengths as short as 35 mm and as long as 120 mm (Tack 1980).

Considerable information exists on growth of grayling in Alaska after the first year, but comparisons of fish in one system with those in another are difficult because of differences among researchers in times of collection, in sample sizes, in methods of analysis, and in age interpretation. A general notion of the growth of grayling in Alaska can be obtained by plotting the mean lengths at capture by age (up to age 8) reported in studies supported by fairly large samples of fish (Fig. 2). From this analysis, three conclusions can be drawn: First, there is considerable variation in grayling size by age in different stream systems. Mean lengths at a given age differ by as much as 100 to 200 mm between fish in the slowest and fastest growing populations. Second, the variation in growth is much less in systems within certain geographic regions of the state. Within a given region,

the range in mean length by age is usually less than 50 mm. And third, grayling grow slowest in northern Alaska and fastest in western Alaska. Growth rate in the interior is midway between that in the northern and western populations.

The growing season for grayling of interior Alaska, as determined by tagging and recapture studies, is short and generally extends over the 3-month period from mid-May to mid-August (Van Wyhe 1964). Although grayling experience some growth during the rest of the year, the increment in length may be as little as one-tenth of the summer increment (Roguski 1967).

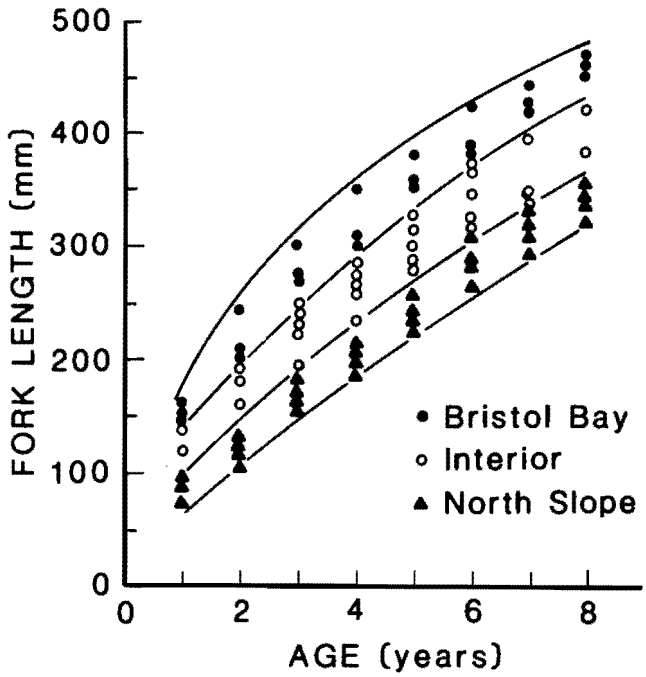

Figure 2. Mean length by age of Arctic grayling from selected systems in Alaska (data from Reed 1964; Van Hulle 1968; Paddock 1968, 1969; McCart et al. 1972; Tack 1973; Craig and Poulin 1975; Kramer 1975; Pearse 1978; Peckham 1978).

Food and Feeding Habits

Larval and adult aquatic insects are the major food of Arctic grayling in Alaska. The fish feed mostly on larval forms in some waters or at certain times (Wojcik 1953; Yoshihara 1972; Furniss 1974, 1975), but on mostly adult forms in other areas (Van Wyhe 1964, de Bruyn and McCart 1974). In streams, most grayling appear to take food from the water surface or the drift and not from the stream bottom (Vascotto 1970, Vascotto and Morrow 1973). In autumn, however, they may feed on the bottom when benthic drift is reduced (Morrow 1980).

Although zooplankton may constitute a large proportion of the diet of grayling (Wojcik 1954, Yoshihara 1972), aquatic insects are still often the major food item (Allin 1957, Reed 1964). Grayling may also feed more on the bottom in lakes than in streams, as indicated by the number of gastropods found in grayling taken from lakes (Wojcik 1954, Yoshihara 1972).

The importance of terrestrial insects in the diet of Arctic grayling in Alaska is not well known because most studies do not distinguish them from the aquatic forms. Nevertheless, Craig and Poulin (1974) found terrestrial insects to be important food items in the grayling examined from Weir Creek and Kavik River. In the Firth River, near the Alaska-Yukon border, de Bruyn and McCart (1974) found that of 136 grayling examined, Coleoptera (of terrestrial origin) occurred in 14.7% of the feeding fish. Terrestrial insects are no doubt more available to grayling inhabiting the smaller streams with dense streamside vegetation. For example, in Shaw Creek, a relatively narrow tributary to the Tanana River that has considerable streamside vegetation, grayling fed mostly on terrestrial insects (Reed 1964).

At certain times of the year, and in some systems, food other than insects may constitute a large part of the diet. Grayling sometimes concentrate near spawning salmon and feed heavily on salmon eggs (Schallock 1966, Alt 1980); they also feed on the eggs of inconnu, (*Stenodus leucichthys*) (Alt 1969), and occasionally on eggs of their own kind (Warner 1958). Fish normally are not a part of the grayling diet, but grayling in the Gulkana River (a tributary of the Copper River) were reported to eat fry of sockeye salmon (*Oncorhynchus nerka*) in large numbers (Williams 1969), and in some Canadian lakes near the Alaska-Yukon border they fed on the ninespine stickleback (*Pungitius pungitius*) (de Bruyn and McCart 1974). Some of the more unusual items found in the stomachs of grayling include shrews (de Bruyn and McCart 1974, Alt 1978) and lemmings (Reed 1964). Grayling venturing into brackish waters along the Beaufort Sea coast may feed on marine isopods and other crustaceans (Tack 1980).

In summer, grayling are active feeders. In the Delta Clearwater River, during June and early July, grayling fed on a 24-hour basis and later in the year ceased feeding only during darkness (Reed 1964). Active feeding habits are evident from the small number of empty stomachs seen during studies of food habits. Reed (1964) found no empty stomachs among 1,300 grayling collected from 13 watersheds in Alaska. Others have also found either no empty stomachs or very few (Yoshihara 1972, de Bruyn and McCart 1974).

Although grayling often live in proximity to other fish, few studies have been done on interspecific competition for food. In a study of the food of grayling, whitefish and lake charr (*Salvelinus namaycush*) in Tangle Lakes (Tanana River drainage), Wojcik (1954) concluded that the three species do not compete with each other for food. Grayling fed mostly on zooplankton and the whitefish on benthic organisms; although lake charr fed on both zooplankton and benthos when young, they ate other fish when older. Wojcik also observed that grayling in the Delta Clearwater River fed ac-

TABLE 5. POPULATION ESTIMATES FOR GRAYLING LONGER THAN 150-MM FORK LENGTH IN INDEX SECTIONS OF THE CHENA RIVER, 1968 TO 1979 (FROM HALLBERG 1980)

River section and year		Dates	Grayling per mile
River mile 6-8	1971	Aug 30-Sept 3	613
(University Ave. to	1972	June 22-26	497
Peger Rd. in Fairbanks)	1973	July 10-13	469
	1974	June 26-28	104
	1976	Aug 19-21	413
	1977	Aug 5-8	511
	1978	July 1-3	91
	1979	July 1-3	91
River mile 8-11	1968		1,095
(Peger Rd. to Wendell	1969		1,890
St. in Fairbanks)	1970	July 2-10	1,479
	1971	Aug 30-Sept 3	2,095
	1972	June 22-26	978
	1973	July 3-10	679
	1974	June 25-28	642
	1976	July 22-24	654
	1977	July 11-14	511
	1978	July 25-28	259
	1979	July 26-30	321
River mile 26.5-29.5 (2-5 miles above mouth of Little Chena River)	1979	Aug 20-23	283
Dam site	1972	June 27-29	1,306
(near river mile 45)	1973	July 18-19	800
	1974	July 9-11	416
	1976	Aug 4-6	489
	1977	July 26-30	507
	1978	Aug 8-11	553
	1979	July 17-20	308

tively at or near the water surface whereas whitefish tended to live in deep holes and were less active. By contrast, Pearse (1974) compared the organisms in the stomachs of two round whitefish and Arctic grayling and concluded that both species preferred, and possibly competed for, the same food items. Where juvenile Arctic charr and grayling occur together, they may feed on similar food items (Craig and Poulin 1975).

I found one reference to the food and feeding of young-of-the-year Arctic grayling in Alaska. Elliott (1980) determined the taxa of aquatic invertebrates eaten by 80 young-of-the-year grayling captured in streams along the route of the trans-Alaska pipeline. Immature stages of chironomid midges were most often eaten, although up to 18 other taxa were also found in the stomachs (Elliott 1980, 1982). Insects of terrestrial origin were consumed in greater numbers as the season progressed and finally surpassed the number of aquatic invertebrates in two of the stream systems. Young-of-the-year grayling stocked in barren lakes depended heavily on midge pupae (Tim Jennings, Alaska Cooperative Fishery Research Unit, pers. comm.). Brown and Buck (1939) reported that under hatchery conditions some grayling fry began eating 4 days after hatching and all fish were feeding by the eighth day, at a water temperature of 11°C.

POPULATION ESTIMATES

Determining the number of grayling in the rivers, streams, and lakes of Alaska is difficult. Ice and floods have made the effective operation of weirs nearly impossible, and mark-recapture studies usually estimate only the proportion of a population that the sampling gear is capable of taking.

Most studies have been designed to estimate the grayling population in selected sections of a river. By repeating these estimates in the same areas year after year, long-term trends in the relative abundance of grayling may become apparent (Table 5). Usually these estimates have been made by capturing grayling with a boat-mounted electrofishing unit (Van Hulle 1968), marking and releasing the fish for 2 to 3 days, and recapturing the fish with the same gear to determine a ratio of marked to unmarked fish on a later day. Due to the selectivity of electrofishing gear for larger grayling, only fish longer than 150 mm were captured in most studies. In other studies hook and line, gill nets, and seines have been used as collecting gears for population estimates (Roguski and Tack 1970, Engel 1973, Hammerstrom 1975, Alt 1976, Gwartney 1980).

The largest number of grayling found in any one location in Alaska was in a stream between Long Tangle Lake and Lower Tangle Lake, about 20 miles west of Paxson. By using hook and line, Roguski and Tack (1970) estimated 36,985 grayling of "catchable" size were in this stream. They concluded that the area was a major feeding area for fish from most of the Tangle Lakes system.

At the outlet of Lower Ugashik Lake in Bristol Bay, numbers of catchable grayling have been estimated to range from 1,180 to 2,053 (Paddock and Whitehead 1970, Siedelman and Cunningham 1972, Gwartney 1980). Although this area provides some of the finest grayling fishing in Alaska, only 159 of the fish were estimated to be of "trophy" size—i.e., 1.36 kg or heavier (Siedelman and Cunningham 1972).

Some of the lakes to which only a hundred or so grayling were transplanted now support spawning populations of nearly 2,000. In Crescent Lake, near Moose Pass on the Seward Highway, Engel (1973) used seines and gill nets to estimate an adult population of 1,756. In Bench Lake, also on the Kenai Peninsula, a population of 1,931 adults was estimated by Hammerstrom (1975) using gill nets and hook and line.

Estimates of numbers of grayling per mile in selected rivers of Alaska have ranged from 42 to 2,095 (Tables 5 and 6). As an index of abundance, these estimates may show trends in population fluctuation. For instance, in the section of the Chena River from Peger Road to Wendell Street (river mile

8 to 11) and at the dam site (near river mile 45), grayling numbers seemingly declined: estimates in 1979 equaled only about one-third of those made 7 to 10 years earlier (Table 5).

RECOMMENDATIONS

Although much information has been gathered on the life history of Arctic grayling in Alaska, several major gaps remain. Some of these gaps may be critical to the future management of grayling, especially as land and resource development and angler pressure continue to increase. Although any further information on the habitat requirements and life history of Arctic grayling will help us to understand and better manage the species, needs for certain data are more strongly indicated than others.

1. *Studies of the early life history, especially the first year of life, of Arctic grayling*. Alteration of habitat may have a greater effect on grayling during their first year than at any other time. What are their habitat requirements? What do they eat? How long do they remain in the vicinity of their hatching site? Do they compete with young round whitefish, chinook salmon (*Oncorhynchus tshawytscha*), Dolly Varden charr, or other species for food and space? Tiny larval grayling are easily harmed by changing environmental conditions. What are some of the major causes of mortality among young grayling?

2. *Identities of discrete stocks of Arctic grayling*. Despite nearly 30 years of investigations of the migrations of Arctic grayling, little is yet known about the migrations and population dynamics of individual stocks. Do grayling home to reproduction sites? What stocks contribute to the major Alaska grayling fisheries? What are the harvest rates of individual stocks in our most popular grayling sport fisheries? Are some stocks being overharvested? What level of harvest can grayling sustain?

   Two areas of research may help in answering these questions. (1) Young often grow at different rates within a given river system. Hence, scale analysis of young-of-the-year grayling may provide a means of stock separation within some systems. (2) If young grayling stay a month or two near the site where they were hatched, coded wire tagging of individual stocks may be feasible. This technique may make it possible to identify the migration patterns of individual stocks, their contributions to mixed stock fisheries, and their harvest rates within those fisheries.

3. *More detailed information on the food of Arctic grayling for studying and predicting the effects of various habitat alterations*. Studies are under way or planned to determine the primary and secondary productivity and ecology of aquatic insects in the upper Chena River. Other studies are planned to determine the effects of placer mining on primary productivity and aquatic insects. Thus far, only general food categories are known for the Arctic grayling. It is especially important to determine the life stages of aquatic insects that are consumed, and to distinguish insects of aquatic origin from those of terrestrial origin.

4. *Studies to determine the effects of stream channelization, flood control, placer mining, riparian vegetation removal, and other habitat alterations on Arctic grayling*. There have been almost no studies of the effects of environmental changes on Arctic grayling in Alaska.

5. *Research into the culture of grayling in hatcheries and best methods of stocking them into rivers*. The future success of some river fisheries may depend on supplemental stocking of hatchery fish. Which stocks might provide the best returns? It is especially important to determine methods of rearing grayling to a size that will insure high survival after stocking. Hence, experimental feeding and rearing studies of Arctic grayling in hatcheries are needed.

6. *Studies of the validity of aging Arctic grayling from scales*. Several investigators have mentioned the difficulty in aging grayling by their scales, especially after age 5. Recent studies indicate a considerable difference in age interpretation, depending on whether scales or otoliths are used. Comparing age interpretations by scales, polished otoliths, pre-opercular bones, and perhaps vertebrae from

TABLE 6. POPULATION ESTIMATES[a] OF GRAYLING PER MILE IN SELECTED RIVERS IN ALASKA

River	Grayling per mile
Kuparuk (Alt 1976)	
1975	145
Lower Goodpaster (Peckham 1979)	
1973	770
1974	323
1975	760
1976	563
1977	604
1978	749
Salcha (Tack 1973, Kramer 1975)	
1972	805
1975	1,224
Upper Susitna (ADF&G 1981)	
1981 (Clearwater tributaries,	501
Main Susitna)	121
Talachulitna (Kubik and Chlupack 1975)	
1974	42

[a]All estimates were based on capture by boat-mounted electrofishing unit except by Alaska Department of Fish and Game (1981) and Alt (1976) who used hook and line.

the same fish may help to determine the validity of using only scales.

Between 1982 and 1985 several studies were completed that provide information relating to the foregoing recommendations. Although the studies do not alter the recommendations, readers should be aware that some of the studies have made considerable progress toward answering the questions that I raised. In addition to references appearing after 1982 on grayling in Alaska contained in the comprehensive bibliography (Armstrong et al. 1986), I draw readers' attention to the following studies, fully listed in the Literature Cited section: Anderson (1984) for effects of habitat alteration; Hop (1985) for stock identity; Jennings (1983) for stocking experiments; Lee (1985) for species interactions in young fish; Ridder (1983, 1984) for life cycles of particular stocks; Sikstrom (1983) for techniques in age determination; Simmons (1983), Van Nieuwenhuyse (1983), and Wagener (1984) for effects of sedimentation from placer mining; Walker (1983) for growth of young fish; and West (1982) for effects of heavy metals.

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INDEXED BIBLIOGRAPHY OF THE HOLARCTIC GENUS THYMALLUS (GRAYLING) TO 1985

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INTRODUCTION

This bibliography contains 1,314 published and unpublished references on the genus *Thymallus* (Cuvier, 1929) to 1985. The references are listed alphabetically by author; multiple publications by the same author are listed by year of publication, the earliest being listed first.

The title of each reference is in the original language following the year of publication. Insofar as possible English translations of foreign titles are given in parentheses, and the language of each foreign reference is shown at the end of the reference. References from Czechoslovakia are listed as Czech (includes Czech and Slovak) and all references from Yugoslavia are listed as Serbo-Croatian. When possible, we have given the entire names of journals and reports. Abbreviations were used only when we were unable to determine full journal names. Each reference is numbered, and these numbers are used in the taxonomic, geographic, and subject indexes. Key words were selected for papers that we were able to obtain (indicated by asterisks in the list), or from the titles or abstracts of others.

For the taxonomic index we have used the scientific name provided by the authors. No attempt was made to combine synonyms, and we have retained subspecies names if given. For references in which no scientific name was provided we have used the most likely taxon. As an aid to using the taxonomic index we provide the following list of species, subspecies, and infrasubspecies together with their common names:

SPECIES:

Thymallus arcticus (Pallas, 1776)—Arctic grayling
Thymallus brevirostris (Kessler, 1879)—Mongolian grayling
Thymallus nigrescens (Dorogostajskij, 1923)—Kosogol grayling
Thymallus thymallus (Linnaeus, 1758)—European grayling

SUBSPECIES:

Thymallus arcticus arcticus (Svetovidov, 1936)—Siberian grayling
Thymallus arcticus baicalensis (Dybowski, 1874)—(Black) Baikal grayling
Thymallus arcticus grubei (Dybowski, 1869)—Amur grayling
Thymallus arcticus mertensi (Valenciennes, 1848)—Kamchatka grayling
Thymallus arcticus pallasi (Valenciennes, 1848)—East Siberian (Vostok-Siberian) grayling
Thymallus brevirostris kozovi (Dashidorzhi et al., 1968)—Mongolian Kozovi grayling

INFRASUBSPECIES:

Thymallus arcticus baicalensis infrasubspecies *brevipinnis* (Svetovidov, 1936)—(White) Baikal grayling
Thymallus arcticus grubei natio *mertensi* (Valenciennes, 1848)—Anadyr/Kamchatka grayling

Arctic and European grayling have appeared in the literature under a variety of synonyms. *Thymallus arcticus* (Pallas, 1776) in North America was previously, before Walter's (1955) work, classified as the following species:

Thymallus (arcticus) signifer (Richardson, 1823)—Arctic grayling
Thymallus montanus (Milner, 1874)—Montana grayling
Thymallus ontariensis (Cuvier and Valenciennes)—Ontario grayling (based on only two specimens)
Thymallus tricolor (Cope, 1865)—Michigan grayling

An old synonym used for Arctic grayling is:
Thymallus lewisii (Henshall, 1898)—Montana grayling

European grayling, *Thymallus thymallus* (Linnaeus, 1758), has sometimes been listed with following synonyms:

Coregonia thymallus (LaCépède, 1803; Noreau, 1911)
Salmo thymallus (Linnaeus, 1758)
Thymallus arcticus (Borisov, 1923)
Thymallus delanis (Valenciennes)
Thymallus gymnogaster (Valenciennes)
Thymallus gymnothorax (Valenciennes)
Thymallus microlepis (Steindachner)
Thymallus thymallus (Regan, 1911; Ekman, 1922; Berg, 1916; Domracev and Pravdin, 1926)
Thymallus thymallus kamensis (Lukas, 1929)
Thymallus thymallus morpha *lacustris* (Balon, 1962)
Thymallus vexillifer (Agassiz, 1848; Valenciennes, 1848; Heckel and Kner, 1858; Blanchard, 1866; Fatio, 1890)
Thymallus vulgaris (Nilsson, 1863; Siebold, 1863; Kessler, 1864; Smitt, 1895; Otterstrom, 1914; Thienemann, 1926)

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A geographic index is provided by country. For the United States, Canada, and the British Isles we have further indexed the references by state, province, or country.

The subjects chosen for the key word index were the ones that we believed would best fit a bibliography on grayling; they were not taken from a standard thesaurus. The key words were interpreted broadly in indexing the references (e.g., the key word "competition" includes both intra- and interspecific competiton). References not available for review by us may contain information on additional subjects not mentioned in the index.

The references that we obtained are on file at the Alaska Cooperative Fishery Research Unit, 138 Arctic Health Building, University of Alaska, Fairbanks, Alaska 99775-0110. In general the references are available for use within the Arctic Health Building only. If, however, it is impossible to obtain a reference of interest from a library or from the distributing agency, a photocopy can be obtained (for a fee) by writing to this address. For Alaska, all Federal Aid in Fish Restoration Reports dealing with Arctic grayling through 1980 have been compiled, bound, and indexed (Armstrong 1982; see review article this volume). This compilation is available for use at the Unit office, and can also be obtained from the Rasmuson Library, University of Alaska, Fairbanks.

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The key words used were:

THYMALLUS, ARCTIC GRAYLING, GRAYLING, HARR, HARJUS, LIPAN, KHARIUS, EUROPEAN GRAYLING, VLAGZALM, TEMOLO, STALLING, AESCHE, ASCHE, LIPIEN, PENZES, OMBRE.

In addition to the computer searches listed above we have hand searched the literature cited sections of the references that we have on file. Other sources hand searched were the following:

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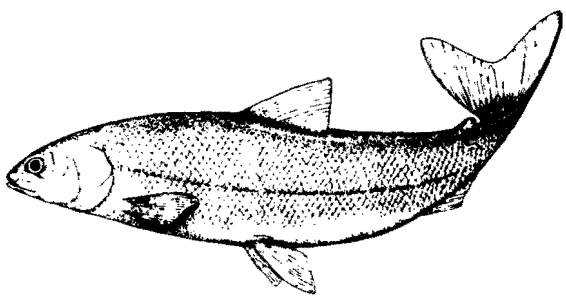

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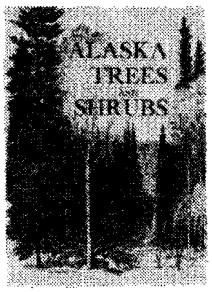

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